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Ship and installation program optimal stationing of Naval ships

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THESIS

**SHIP AND INSTALLATION PROGRAM:
OPTIMAL STATIONING OF NAVAL SHIPS**

by

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June 2006

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Beginning in 1988, Congress authorized the Department of Defense (DoD) to conduct five rounds of Base Realignment and Closure (BRAC) including the most recent round in 2005. BRAC provides the DoD with a politically insulated evaluation and reorganization of its installations. For BRAC 2005, the Department of the Navy (DoN) used an integer linear program called Configuration Analysis to determine installation closures. Using constraints that maintain adequate pier capacity and unique capability installations, Configuration Analysis seeks to maximize a measure of military value while penalizing excess capacity for a set of open installations. This thesis extends the Navy's Configuration Analysis to incorporate cost and ship stationing for the set of surface and subsurface installations. We call the modified integer linear program Ship and Installation Program (SHIP). SHIP provides a minimum cost stationing for the given set of surface and subsurface ships and installations while maintaining operational feasibility and a required level of military value. Using data mainly drawn from the DoN BRAC 2005 data call, we evaluate the tradeoff between cost and military value using SHIP's 20-year net present value (NPV). Requiring higher levels of aggregate military value results in higher cost, expressed in SHIP as higher NPV. Conversely, accepting lower levels of military value could potentially allow the DoN to realize $3.2 billion in savings. We also investigate the influence of using two different measures of pier capacity and incorporate 30 new ships and submarines to demonstrate SHIP's ability to station the proposed future force structure.

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OPTIMAL STATIONING OF NAVAL SHIPS**

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ABSTRACT

Beginning in 1988, Congress authorized the Department of Defense (DoD) to conduct five rounds of Base Realignment and Closure (BRAC) including the most recent round in 2005. BRAC provides the DoD with a politically insulated evaluation and reorganization of its installations. For BRAC 2005, the Department of the Navy (DoN) used an integer linear program called Configuration Analysis to determine installation closures. Using constraints that maintain adequate pier capacity and unique capability installations, Configuration Analysis seeks to maximize a measure of military value while penalizing excess capacity for a set of open installations. This thesis extends the Navy's Configuration Analysis to incorporate cost and ship stationing for the set of surface and subsurface installations. We call the modified integer linear program Ship and Installation Program (SHIP). SHIP provides a minimum cost stationing for the given set of surface and subsurface ships and installations while maintaining operational feasibility and a required level of military value. Using data mainly drawn from the DoN BRAC 2005 data call, we evaluate the tradeoff between cost and military value using SHIP's 20-year net present value (NPV). Requiring higher levels of aggregate military value results in higher cost, expressed in SHIP as higher NPV. Conversely, accepting lower levels of military value could potentially allow the DoN to realize $3.2 billion in savings. We also investigate the influence of using two different measures of pier capacity and incorporate 30 new ships and submarines to demonstrate SHIP's ability to station the proposed future force structure.

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EXECUTIVE SUMMARY

Since 1988, Congress has authorized the Department of Defense (DoD) to conduct five rounds of Base Realignment and Closure (BRAC) including the most recent round in 2005. BRAC provides the DoD with a politically insulated evaluation and reorganization of its installations. With BRAC, the services take a critical look at infrastructure and determine recommendations for how the DoD can have the most valuable balance of efficiency and affordability across its infrastructure. Each service conducts their own data collection and analysis, and then provides recommendations to the Secretary of Defense. In 2005, the services' modeling and analysis differed.

For BRAC 2005, the Department of the Navy (DoN) used an integer linear program called Configuration Analysis to help determine installation closures. Using constraints that maintain adequate pier capacity and unique capability installations, Configuration Analysis seeks to maximize a measure of military value while penalizing excess capacity for a set of open installations. The Army also used an integer linear program called Optimal Stationing of Army Forces (OSAF). In addition to modeling operational feasibility and military value, OSAF also considers the cost of stationing a given force structure. While both Configuration Analysis and OSAF model the closure of installations, OSAF also prescribes where to station individual units at open installations.

This thesis extends the Navy's Configuration Analysis to incorporate cost and ship stationing for the set of surface and subsurface installations. We call the modified integer linear program Ship and Installation Program (SHIP). SHIP provides a minimum cost stationing for the given set of surface and subsurface ships and installations while maintaining operational feasibility and a minimum level of military value.

SHIP includes fixed costs, variable costs, and one-time costs. Fixed costs are the costs of keeping an installation open regardless of what ships are stationed there. Variable costs are the location specific costs associated with operating a ship at a given installation. One time costs are the costs of moving a ship from one installation to

another. We incorporate these into our objective function to minimize cost, expressed in SHIP as the 20-year net present value (NPV), while maintaining operational feasibility.

SHIP contains 236 ships of 13 classes currently stationed at 15 installations. SHIP models the movement of individual ships for each stationing scenario. Ships stationed at installations that SHIP closes must move to other installations. In addition, SHIP allows ships to move from non-closing installations if it is operationally feasible and results in a decrease in 20-year NPV. This results in more flexible stationing alternatives; an installation does not necessarily have to close for a ship to be moved to a more cost effective location. At each level of required military value, SHIP identifies the ships that move and the gaining and losing installations.

SHIP provides the optimal set of installations that minimizes the 20-year NPV while maintaining a required level of military value. We evaluate the tradeoff between cost and military value using SHIP's 20-year NPV. Requiring higher levels of aggregate military value results in higher cost, expressed in SHIP as higher NPV. Conversely, accepting lower levels of military value could potentially help the DoN save $3.2 billion.

SHIP recommends similar installation closures to those proposed by the DoN for BRAC 2005. In addition, SHIP identifies alternate solutions that current Configuration Analysis does not generate. Because the DoN does not currently examine cost until after Configuration Analysis runs, they may not identify these alternative solutions, and cannot easily examine the tradeoff between military value and cost. SHIP determines the most cost-effective, feasible stationing alternatives.

We investigate two measures of pier capacity. The first, Cruiser Equivalents (CGEs), is a measure that DoN uses to transform the pier space at each installation into the number of Cruisers it is capable of supporting. The second, linear feet, is a measure of an installation's linear feet of pier space. The DoN Military Value Data Call for BRAC collects this data. We use both capacity measures in SHIP and find results differ somewhat depending on which measure it uses. SHIP closes more installations when using linear feet because there is more excess pier capacity when the capacity metric is linear feet.

We incorporate 30 new ships and submarines that will be joining the fleet in the near future to demonstrate SHIP's ability to station a proposed future force structure. We then evaluate the tradeoff between 20-year NPV, military value, and future expandability of the force structure in terms of pier capacity. Reducing the 20-year NPV and corresponding military value leads to a decrease in the Navy's ability to expand its future force structure and still have sufficient pier capacity. With the ability to model future stationing, SHIP directly accounts for future pier capacity requirements.

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I. INTRODUCTION

A. PROBLEM DEFINITION

Since 1988, Congress has authorized the Department of Defense (DoD) to conduct five rounds of Base Realignment and Closure (BRAC) including the most recent round in 2005 [DoD 2004]. BRAC provides the DoD with a politically insulated evaluation and reorganization of its installations. With BRAC, the services take a critical look at infrastructure and determine recommendations for how the DoD can have the most valuable balance of efficiency and affordability across its infrastructure [Defense Base Closure and Realignment Commission 2005]. Each service conducts their own data collection and analysis, and then provides recommendations to the Secretary of Defense. In 2005, the services' modeling and analysis differed.

For BRAC 2005, the Department of the Navy (DoN) used an integer linear program called Configuration Analysis to help determine installation closures. Using constraints that maintain adequate pier capacity and unique capability installations, Configuration Analysis seeks to maximize a measure of military value while penalizing excess capacity for a set of open installations. The Army also used an integer linear program called Optimal Stationing of Army Forces (OSAF). In addition to modeling operational feasibility and military value, OSAF also considers the cost of stationing a given force structure. While both Configuration Analysis and OSAF model the closure of installations, OSAF also prescribes where to station individual units at open installations.

This thesis extends the Navy's Configuration Analysis to incorporate cost and major units in a manner similar to OSAF for a set of surface and subsurface installations. The modified integer linear program is called Ship and Installation Program (SHIP). SHIP prescribes a minimum cost stationing for a given set of surface and subsurface ships at installations and installation closures, while maintaining operational feasibility and a required level of military value.

B. BACKGROUND

1. Some BRAC History

The DoD conducts BRAC to update and reorganize its infrastructure across all services. The goal of BRAC is to reorganize force structure on installations in the continental United States, Hawaii, Alaska, and U.S. territories while retaining operational readiness. Each service conducts data collection and analysis, and then provides recommendations via the Secretary of Defense to the Presidential BRAC Commission. The Commission approves or disapproves each recommendation based on a list of selection criteria before forwarding a complete list of recommendations to the President. The President may approve or disapprove the list; if it is disapproved, the Commission may revise their recommendations. Given the President's final approval, Congress has 45 days to disapprove the complete list of recommendations, or it becomes law. The DoD implements the recommendations according to BRAC implementation schedules throughout the following years [DoD 2006].

Congress authorized the first round of BRAC in 1988. Three more rounds took place during 1991, 1993 and 1995. BRAC 2005 is the fifth such round of closures and realignments.

2. 2005 BRAC Modeling

a. Navy's Configuration Analysis

The DoN uses an integer linear program, called Configuration Analysis, to generate candidate installation closures to be considered for additional analysis. The DoN categorizes its installations by their unique functions into four major areas: Operations, Headquarters and Support Activities, Education and Training, and Other Activities. Each major area is further divided into subcategories. The Operations area includes surface and subsurface, aviation, ground and munitions subcategories. Table 1.1 lists the number of installations in each Operations subcategory.

Subcategory	Number of Installations
Surface/Subsurface	30
Aviation	35
Ground	11
Munitions	11

Table 1.1: Navy Operations major area subcategories and number of installations. This thesis examines the Surface/Subsurface subcategory.

The DoN conducts capacity analyses on all subcategories of installations and, if excess capacity exists, a military value analysis of all installations within that subcategory. They then combine the two analyses into a Configuration Analysis. This optimization model's objective function expresses military value for a set of retained installations combined with a penalty for retained capacity. In order to generate outcomes that are operationally feasible, the model's constraints ensure adequate pier space and maintain at least one CVN and one SSBN capable installation on each coast. The Configuration Analysis determines feasible sets of installations, which can then be analyzed further to develop BRAC recommendations. This allows the analysts to examine the exchange between reduction in excess capacity and retention of military value [DoN 2005]. Configuration Analysis does not consider cost, a crucial focus of BRAC [DoN Infrastructure and Analysis Team 2005], nor does it directly consider stationing of individual ships. Appendix A provides the formulation for the Configuration Analysis for Surface and Subsurface installations.

b. OSAF

The Army uses OSAF, an integer linear program, to help analyze stationing alternatives. OSAF considers unit requirements and stationing restrictions as well as military value and cost. A primary input for OSAF is a "major unit," an aggregate of units that must be stationed at the same location. OSAF minimizes the 20-year Net Present Value (NPV) of stationing a given force structure, while ensuring adequate facilities and training lands for units and taking into account special stationing restrictions. OSAF has been used to aid in many stationing decisions, including BRAC

2005. OSAF includes fixed costs, variable costs, and one-time costs [Center for Army Analysis 2005]. Appendix B provides an OSAF formulation.

C. EXTENDING CONFIGURATION ANALYSIS

We focus our study on the Surface and Subsurface subcategory with its 30 naval installations. SHIP only includes the 15 naval installations that currently berth surface and subsurface combatants (Table 1.2). The excluded installations have the pier capacity to berth ships, but do not currently do so; we assume they are unavailable for stationing ships. An example of one such installation is Naval Station Newport, which has pier capacity from previously homeporting ships, but currently functions as a training command.

1. Capabilities of Configuration Analysis

The Navy's capacity analysis for naval installations uses Cruiser Equivalents (CGEs) to assess the pier capacity at each installation. CGE is a measure that transforms the pier space at each installation into the number of CGs that it is capable of supporting. Instructions are given to each installation on how to calculate their CGE value [Keenan 2004]. These instructions are subject to interpretation, and therefore could lead to inconsistencies between the number of CGEs and the number of linear feet of pier space reported. The ratio between these two numbers is not constant across all installations.

The Navy's military value analysis attempts to evaluate each installation's ability to support ships and ship personnel, and covers five main areas of interest: operational infrastructure, operational training, port characteristics, environment and encroachment, and personnel support. The Navy's data call consists of 64 questions; the final military value calculation uses 61. Each of the questions has an assigned weight that indicates how much it contributes to an installation's overall military value. Appendix C provides these questions and weights. Installations earn a maximum military value score of 100 points based on their responses. Some questions in the military value calculation require a binary (yes/no) answer; others require a numerical response. The Navy uses "fuzzy functions" to scale non-binary responses into smooth functions over the interval [0,1]. Appendices J and K of the DoN's BRAC 2005: Analysis Handbook describe these fuzzy functions [DoN Infrastructure and Analysis Team 2005].

Installation	CGE Capacity	Military Value
Naval Station Norfolk	97.25	67.51
Naval Amphibious Base Little Creek	27.00	55.90
Naval Station Mayport	32.50	55.71
Naval Station Pascagoula	5.50	37.08
Naval Station Ingleside	13.50	42.23
Naval Submarine Base New London	16.25	50.68
Naval Submarine Base Kings Bay	13.50	63.51
Naval Station Everett	12.00	50.68
Naval Station Bremerton	14.00	63.25
Naval Station San Diego	87.00	61.43
Naval Station Pearl Harbor	49.75	74.50
Naval Station Guam	11.00	47.67
Naval Submarine Base Point Loma	10.50	58.29
Naval Submarine Base Bangor	7.75	62.98
Naval Air Station North Island	20.00	59.68

Table 1.2. SHIP Installations, CGE Capacity, and Military Value. CGE capacity measures pier capacity at each installation. Military value scores each installation based on their ability to support ships and ship personnel.

When combining the two analyses into the Configuration Analysis for naval installations, the DoN includes five constraint sets to ensure operational feasibility: overall CGE requirements, coastal CGE requirements, coastal SSBN requirements, overall CVN requirements, and coastal CVN requirements. These constraints guarantee that, no matter what set of installations remains open, the required pier space and coastal capabilities are met. Due to special requirements, not all installations are capable of homeporting all ships. For example, nuclear powered submarines and aircraft carriers can only be homeported at specific installations. The model accounts for these restrictions.

The objective function of the Configuration Analysis maximizes the retained military value while penalizing retained excess capacity (and/or the number of open activities) [Nickel 2004].

2. Extend Configuration Analysis

a. Incorporate Cost

While BRAC's main focus is to transform installation infrastructure to support a modernized military, it also attempts to reduce costs to produce future savings.

The Configuration Analysis, however, does not consider cost. The CGE constraints address pier space requirements, and coastal capability constraints ensure pier capacity for ships and submarines. By introducing cost into SHIP, in a similar fashion to OSAF, we believe that the Navy's BRAC integer linear program can be improved. This information is crucial to carrying out BRAC, as evidenced by DoD's reliance on Cost of Base Realignment Actions (COBRA), DoD computer software used to estimate costs and savings associated with BRAC recommendations [R&K Engineering 2005a]. If cost is an important factor, and the data is readily available, exclusion could be seen as a limitation.

SHIP includes fixed costs, variable costs, and one time costs. Fixed costs are the costs of keeping an installation open regardless of what ships are stationed there. Variable costs are the location specific costs associated with operating a ship at a given installation. One time costs are the costs of moving a ship from one installation to another. We incorporate these costs into SHIP's objective function to express the 20-year NPV, as currently done in COBRA, while maintaining operational feasibility.

b. Incorporate Major Units

The Navy's Configuration Analysis models each installation's attributes, but does not directly consider stationing of individual ships. By including ship and submarine stationing in SHIP, the DoN can provide more flexible stationing alternatives. For example, this allows the model to take advantage of a more cost effective alternative by moving ships without necessarily closing installations. It also provides a prescription for where ships should be homeported to realize the most savings, while accounting for the cost of moving ships.

SHIP's ship list contains 236 ships of 13 classes currently stationed at the 15 installations shown in Table 1.2. Each ship class has a specific pier space requirement given in CGEs, as indicated in Table 1.3 [Keenan 2004]. SHIP allows individual ships to be moved between installations while taking into account operational feasibility and transportation cost.

Ship Class	CGE Capacity Required
CVN – Aircraft Carriers	4.00
FFG – Frigates	0.75
CG – Cruisers	1.00
DDG – Destroyers	1.00
SSBN – Ballistic Missile Submarines	1.00
SSN – Fast Attack Submarines	0.75
LHD/LHA – Amphibious Assault Ships	2.50
LPD – Amphibious Transport Dock	2.00
LSD – Dock Landing Ship	1.50
MCM – Mine Countermeasure Ship	0.50
MHC – Coastal Mine Hunters	0.25
PC – Patrol Coastal Ship	0.25
ARS – Rescue and Salvage Ship	0.50

Table 1.3: Ship Classes. Ship Classes included in SHIP with corresponding CGE capacity requirement.

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II. LITERATURE REVIEW

The services have developed several optimization models to support Base Realignment and Closure decisions. This chapter reviews some of the Navy and Army models used during previous BRAC rounds, as well as similar civilian applications.

The DoN BRAC 95 Analytical Approach and the BRAC 2005: Analysis Handbook describe how the DoN developed BRAC recommendations in 1995 and 2005, respectively. Both rounds include a capacity analysis, military value analysis, and configuration analysis. In 1995, the Configuration Analysis identified optimal sets of installations that minimize total retained capacity while maintaining average military value across installations [DoN Base Structure Evaluation Committee 1995]. 2005's Configuration Analysis differs in that the stated objective is to maximize military value while providing a penalty for retained capacity [DoN Infrastructure and Analysis Team 2005]. Operational necessities, such as distributing fleet assets between the east and west coast, constrain the configuration of the retained installations. The optimal solution sets are then used to generate closure and realignment scenarios. COBRA helps determine the costs associated with alternative scenarios. Emphasis is placed on the fact that the solutions generated by the optimization model are not necessarily the installations given in the final BRAC recommendations.

OSAF is an integer linear program, developed by the Center for Army Analysis and the Naval Postgraduate School, which the Army Basing Study (TABS) used to inform analysis during the 2005 round of BRAC [Center for Army Analysis 2005]. OSAF provides an optimal stationing plan for the Army given a force structure, set of installations, and stationing restrictions. OSAF is an integer linear program that minimizes NPV for all fixed and recurring costs over a given time period. Constraints ensure adequate facilities and training lands for units while taking into account operational stationing restrictions. During the 2005 round of BRAC, OSAF helped determine Army stationing plans for more than 600 major units at 87 installations and training areas, as well as 10 major leased facilities.

There have been many extensions of OSAF. Gezer [2001] modifies OSAF to analyze the stationing of US Army forces in South Korea. During 2001, an initiative called the Land Partnership Plan called for the consolidation of the small, isolated installations in South Korea into larger, more enduring installations. Furthermore, the United States Forces in Korea command wants to improve quality of life and increase on-base family housing. This led to the development of Optimal Stationing of Army Forces in Korea (OSAFK), an integer linear program that modifies OSAF to analyze 51 US Army installations in South Korea. OSAFK provides a minimum cost stationing while meeting budgetary and operational requirements.

Richards [2003] implements two relaxations to OSAF that provide more realistic stationing requirements and account for existing facility space shortfalls. The first relaxation allows existing facility shortfalls for units that are not moved to continue. Units that are moved receive all authorized facility space, but units that do not move realistically retain what they currently have. The second relaxation allows the conversion of one type of facility space into another type, with an appropriate cost assigned to the conversion. This allows the Army to use their excess facilities instead of relying solely on new construction.

Dowty [1994] formulates Hospital Efficient Location Program (HELP) to determine which Military Treatment Facilities (MTF) to recommend for closure for BRAC 1995. HELP is a mixed integer linear program that maximizes beneficiary care provided and minimizes cost while ensuring Navy Medical's constraints are met. HELP includes fixed costs of operating an MTF, variable costs of care provided, and expansion costs in its objective function. There are also minimum and maximum capacity constraints for an MTF, as well as system wide budgetary constraints. HELP is an example of a DoN model that minimizes cost in a manner similar to OSAF.

Free [1994] develops a mixed integer linear program to optimize Army Base Realignment and Closure scheduling. Given a set of installations that will be closed or realigned, an integer linear program schedules BRAC actions in order to attain maximum total savings within budgetary constraints. This model later evolved into Base Realignment and Closure Action Scheduler (BRACAS). BRACAS produces a schedule that contains a detailed breakdown of the costs associated with each BRAC action. The U.S. Army Base Realignment and Closure Office used BRACAS during 1995 to help determine budget and implementation schedules for the 1995 closures and realignments [Dell 1998]. TABS used BRACAS in 2005.

COBRA calculates the cost and savings of a given BRAC stationing scenario, and can be used to compare the net savings of different stationing alternatives. The United States Air Force Cost Center developed COBRA with the Logistics Management Institute in 1988 and the BRAC 1988 Commission used the model for cost estimates. The US Army assumed continued development of COBRA in 1989, and tasked R&K Engineering to make improvements to the model. All subsequent rounds of BRAC have utilized COBRA for their cost estimates [R&K Engineering 2005b].

Multiple applications of optimization in the civilian world parallel DoD efforts. Ross and Soland [1977] analyze facility location problems with integer linear programs. Their objective function expresses the cost of a system by assigning certain tasks to certain agents, while setting limitations on resource amounts and the number of tasks assigned to each agent. Current et al [1990] provide a survey of 45 facility location problems and state that many such problems have multiple objective functions. Cost minimization is the traditional objective in facility location problems, but other objectives, such as racial balancing for schools and demand satisfaction for private companies, also influence facility location decisions. They find that most of the articles reviewed fall into four categories: cost minimization, demand oriented, profit maximization, and environmental concern. ReVelle and Eiselt [2005] review the characteristics that define facility location problems and the types of such problems that are currently being investigated. They identify three types of objective functions: "pull" objectives (such as maximizing profit or minimizing distance), "push" objectives (such as maximizing distance to noxious facilities), and achievement of equity (such as providing customers equal access to facilities).

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III. SHIP AND INSTALLATION PROGRAM

A. CAPABILITIES OF SHIP

We investigate the set of Naval Surface and Subsurface installations consisting of the 15 installations listed in Table 1.1. Furthermore, SHIP incorporates all individual ships stationed at the 15 installations.

SHIP includes fixed costs, stationing costs, and moving costs. The Navy's BRAC data call does not collect any of these costs, so they are drawn from other sources, including COBRA, Visibility and Management of Operating and Support Costs (VAMOSC), and Defense Finance and Accounting Service (DFAS).

SHIP expresses the 20-year NPV of stationing a given set of ships at Navy Surface and Subsurface Installations that currently berth ships. Constraints ensure operational feasibility while maintaining retained military value above a given level. SHIP provides output indicating which installations remain open and at which installation each ship is stationed.

B. SHIP MODEL FORMULATION

1. Indices and Sets

i	installations
s	ships
$i \in east$	Set of installations on the East Coast
$i \in west$	Set of installations on the West Coast
$i \in eastSSBN$	Set of installations on the East Coast that can homeport SSBNs
$i \in westSSBN$	Set of installations on the West Coast that can homeport SSBNs
$i \in eastCVN$	Set of installations on the East Coast that can homeport CVNs
$i \in westCVN$	Set of installations on the West Coast that can homeport CVNs
$i \in CA_s$	Set of installations where ship s can be stationed

$s \in IS_i$	Initial stationing of ships at installation *i*
$s \in SA_i$	Set of ships that can be assigned to installation *i*
$s \in SAC_i$	Set of CVNs that can be assigned to installation *i*
$s \in SAB_i$	Set of SSBNs that can be assigned to installation *i*

2. Parameters

<u>Cost Data (units)</u>

$fcost_i$	Fixed cost of keeping installation *i* open ($)
$statcost_{i,s}$	Cost of stationing ship *s* at installation *i* ($)
$movecost_{i,s}$	Cost of moving ship *s* to installation *i* ($)

<u>Military Value Data (units)</u>

mv_i	Military value for installation *i* (MV)
$mvBase$	Minimum military value requirement (MV)

<u>Capacity Data (units)</u>

cge_i	Pier capacity at installation *i* (CGE)
$cgeShip_s$	Pier requirement of ship *s* (CGE)
$cgeReq$	Minimum CGE requirement (CGE)
$cgeReqEast$	Minimum CGE requirement for the East Coast (CGE)
$cgeReqWest$	Minimum CGE requirement for the West Coast (CGE)
$shipReqEast$	Minimum number of ships to be stationed on the East Coast
$shipReqWest$	Minimum number of ships to be stationed on the West Coast
$cvnPier_i$	Number of CVN-capable piers at installation *i*
$cvnPierReq$	Number of CVN-capable piers required
$cvnReqEast$	Minimum number of CVNs to be stationed on the East Coast
$cvnReqWest$	Minimum number of CVNs to be stationed on the West Coast

ssbnReqEast	Minimum number of SSBNs to be stationed on the East Coast
ssbnReqWest	Minimum number of SSBNs to be stationed on the West Coast

Adjusted Present Value (APV) Factor Data

APVss	APV for steady state stationing costs (years 7-20)
APVsq	APV for status quo stationing costs (years 1-6). Note: This assumes that all closures and ship movements take place in the sixth year.
APVfixed	APV for retained installation costs (years 1-20)
APVmove	APV for moving costs

3. Decision Variables

$STATION_{i,s}$	1 if ship *s* is assigned to installation *i*, 0 otherwise
$OPEN_i$	1 if installation *i* remains open, 0 if it is closed

4. Objective Function (Minimize NPV)

MINIMIZE

$$APVfixed \sum_i fcost_i\, OPEN_i + APVss \sum_{i,s \in SA_i} statcost_{i,s}\, STATION_{i,s}$$

$$+ APVsq \left(\sum_{i,s \in IS_i} statcost_{i,s} + \sum_i fcost_i\,(1 - OPEN_i) \right) + APVmove \sum_{\substack{i,s \in SA_i \\ and \\ i,s \notin IS_i}} movecost_{i,s}\, STATION_{i,s}$$

5. Constraints

$$\sum_i mv_i\, OPEN_i \geq mvBase \qquad (1)$$

$$\sum_{i \in CA_s} STATION_{i,s} = 1 \quad \forall s \qquad (2)$$

$$STATION_{i,s} \leq OPEN_i \quad \forall i, s \in SA_i \qquad (3)$$

$$\sum_{s \in SA_i} cgeShip_s\, STATION_{i,s} \leq cge_i \quad \forall i \qquad (4)$$

$$\sum_{s \in SAC_i} STATION_{i,s} \leq cvnPier_i \quad \forall i \qquad (5)$$

$$\sum_i cge_i\, OPEN_i \geq cgeReq \qquad (6)$$

$$\sum_{i \in East} cge_i \, OPEN_i \geq cgeReqEast \qquad (7)$$

$$\sum_{i \in West} cge_i \, OPEN_i \geq cgeReqWest \qquad (8)$$

$$\sum_{\substack{i \in East \\ s \in SA_i}} STATION_{i,s} \geq shipReqEast \qquad (9)$$

$$\sum_{\substack{i \in West \\ s \in SA_i}} STATION_{i,s} \geq shipReqWest \qquad (10)$$

$$\sum_{i} cvnPier_i \, OPEN_i \geq cvnPierReq \qquad (11)$$

$$\sum_{\substack{i \in East \\ s \in SAC_i}} STATION_{i,s} \geq cvnReqEast \qquad (12)$$

$$\sum_{\substack{i \in West \\ s \in SAC_i}} STATION_{i,s} \geq cvnReqWest \qquad (13)$$

$$\sum_{\substack{i \in East \\ s \in SAB_i}} STATION_{i,s} \geq ssbnReqEast \qquad (14)$$

$$\sum_{\substack{i \in West \\ s \in SAB_i}} STATION_{i,s} \geq ssbnReqWest \qquad (15)$$

$$STATION_{i,s} \in \{0,1\} \qquad \forall\, i, s \qquad (16)$$

$$OPEN_i \in \{0,1\} \qquad \forall\, i \qquad (17)$$

a. Military Value Constraints

Constraint (1) ensures that the total retained military value is greater than a certain level.

b. Stationing Requirements

Constraint set (2) ensures that every surface and subsurface ship is stationed at one installation.

Constraint set (3) ensures that ships are only stationed at installations that remain open.

c. Capacity Constraints

Constraints (4) through (13) ensure capacity requirements and constraints are met.

Constraint set (4) ensures that the pier space required by the ships stationed at each installation does not exceed the pier capacity of that installation.

Constraint set (5) ensures the number of carriers stationed at an installation does not exceed the number of carrier piers of that installation.

Constraints (6) to (15) can be expressed as one constraint set, but for clarity, we list each here individually.

Constraint (6) ensures there is adequate pier space retained over all naval surface and subsurface installations.

Constraints (7) and (8) ensure there is adequate pier space retained on each coast.

Constraints (9) and (10) ensure that each coast retains a minimum percentage of all surface and subsurface ships.

Constraint (11) ensures that there are an adequate number of CVN-capable piers retained over all installations.

Constraints (12) and (13) ensure that each coast retains a minimum percentage of all CVNs.

Constraints (14) and (15) ensure that each coast retains a minimum percentage of all SSBNs.

d. Binary Constraints

Constraint sets (16) and (17) declare the binary variables.

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IV. RESULTS

A. MODEL INPUTS

1. Set of Installations

The 2005 Configuration Analysis for surface and subsurface installations originally included thirty installations. The DoN eventually excluded 15 installations that currently do not berth ships or submarines. SHIP further excludes Naval Weapons Stations Earle, as all ships stationed there were decommissioned in 2005. Due to limited data, SHIP fixes Naval Station Ingleside closed; this does not greatly affect results, as the 2005 BRAC Commission approved Ingleside for closure.

2. Force Structure

SHIP includes 236 ships and submarines currently stationed at the surface and subsurface installations listed in Table 1.2. It excludes certain ships that have been decommissioned or are scheduled for decommission in the immediate future. For ease of data collection, certain unique capability ships, such as submarine tenders and command ships, have been excluded. All ships stationed at Ingleside are moved to Naval Station San Diego, as prescribed by BRAC 2005.

3. Model Parameters

The Navy's Configuration Analysis retains a minimum pier capacity in CGEs across all installations. In addition, it requires each coast retain 40% of this capacity. It retains a minimum number of CVN-capable piers across all installations. Each coast must retain at least one SSBN-capable installation.

SHIP imposes similar stationing requirements. It maintains the Configuration Analysis' CGE requirements, as well as CVN-pier requirements. With the inclusion of a major unit list, SHIP requires each coast retain 40% of all ships, as well as 40% of all CVNs and SSBNs. Table 4.1 lists these parameters.

Parameter	Requirement
cgeReq	320
cgeReqEast	136
cgeReqWest	136
shipReqEast	94
shipReqWest	94
cvnPierReq	10
cvnReqEast	4
cvnReqWest	4
ssbnReqEast	6
ssbnReqWest	6

Table 4.1. SHIP Parameters and Requirements. SHIP requires a minimum number of CGEs, ships, CVNs, and SSBNs on each coast.

4. Cost Data

First we consider fixed costs, the costs of keeping an installation open regardless of what ships are stationed there. Using readily available COBRA data, we determine a fixed cost for each installation. We include several COBRA cost categories taken from R&K Engineering [2005b]:

- *Total Sustainment Budget:* Accounts for the cost of maintenance and repair activities necessary to keep installation facilities in good working order.
- *Sustainment Payroll Budget:* The cost of payroll associated with the sustainment requirement for each installation.
- *BOS (Base Operations) Non-Payroll Budget:* The cost of base operations, not including payroll.
- *BOS Payroll Budget:* The cost of base operations payroll.

We also include the cost of the housing allowance for all officers and enlisted stationed at each installation.

The second costs we consider are stationing costs. These are the location specific costs associated with operating a ship; the DoN's VAMOSC website provides these costs [Naval Center for Cost Analysis 2006]. We account for a ship's training and deployment cycles by averaging data for three ships in each class over a period of three years. When there is no data for ships not currently stationed at a given installation, we extrapolate from data we already have. This stationing cost is entirely location dependent. We include seven elements from the VAMOSC data as described by the Cost Analysis Improvement Group [1992]:

- *Petroleum, oil and lubricants (POL) and energy consumption:* Accounts for the cost of POL consumed by a ship, both underway and not underway, for operations and maintenance.
- *Purchased services:* Accounts for the costs of power, water, gas, electricity, telephones, laundry, post office services, and other port services.
- *Commercial industrial services:* Accounts for the costs of privately contracted intermediate maintenance both ashore and afloat.
- *Non-scheduled ship repair*: Includes labor, material, and overhead costs at public and private repair facilities for unforeseen maintenance.
- *Fleet modernization:* Includes material, labor, and overhead costs at both public and private facilities to improve a ship's safety, maintainability, and technical capabilities.
- *Sustaining engineering support:* Includes government and/or contracting engineering services, technical advice, training for component or system installation, operation, and maintenance, and labor, material, and overhead costs due to providing these services.
- *Personnel support costs:* Includes costs of specialty training for personnel replacement, Permanent Change of Station (PCS), and medical care.

The stationing cost does not account for personnel pay and allowances, as these are within fixed costs.

The third and final costs we consider are moving costs. These account for the cost of moving a ship from one installation to another. These data are not easily attainable or calculated. Using a program with various assumptions about the number of personnel moving with a ship, DFAS supplied data for four different size components and three mileages. The size components are small (110 personnel), medium (360 personnel), medium-large (1,050 personnel), and large (3,200 personnel). The mileages are short (900 miles), middle (1,800 miles), and long (2,800 miles). The moving cost includes household goods cost, mileage allowance in lieu of transport, overseas air rates, temporary living expense, dislocation allowance, and non-temporary storage [Klimek 2006]. Although they are not exact for each location and ship class, these 12 combinations of component size and move mileage are applied to each feasible move considered in SHIP.

B. SHIP IMPLEMENTATION

We implement all versions of SHIP in the General Algebraic Modeling System (GAMS) revision 138 [GAMS 2004], and solve them using CPLEX 9.0.0 [ILOG 2004]. SHIP contains approximately 3,500 binary variables and 3,800 constraints. Generation and solution time usually takes less than one second to certify an optimal solution, though some implementations take up to 15 minutes.

We implement four cases of SHIP to evaluate the tradeoff between military value and 20-year NPV. In Case 1, SHIP allows all installations to close. In Case 2, SHIP allows all installations except Pearl Harbor to close. In Case 3, we substitute linear feet for CGEs in SHIP's capacity constraints. In Case 4, we incorporate 30 new ships into SHIP.

C. 20-YEAR NPV VERSUS MILITARY VALUE

SHIP provides the optimal set of installations that minimizes the 20-year NPV while maintaining a required level of military value. In Case 1, we examine how the NPV changes under different levels of military value, allowing all installations to close. The status quo level of aggregate military value, with all installations left open except Naval Station Ingleside, is 808.87. Figure 4.1 shows the tradeoff between lowering the accepted aggregate military value and the NPV. Accepting a military value at 70% of its 2005 status quo yields a 20-year net present savings of approximately $8 billion. We note that lowering the required military value from 95% to 90% of status quo yields a savings of more than $6 billion.

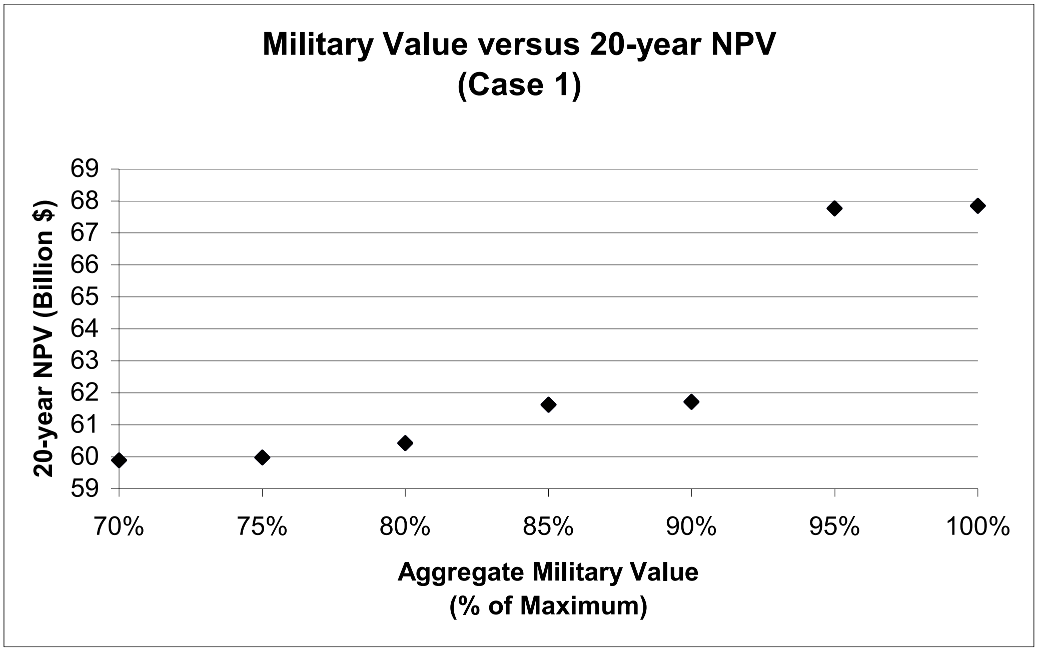

Figure 4.1. Military Value versus 20-year NPV for Case 1. Accepting a decrease in Military Value allows for a decrease in the 20-year NPV. Savings at 70% of maximum military value is approximately $8 billion. Lowering the required military value from 95% to 90% of status quo yields a savings of more than $6 billion.

Table 4.2 shows the installations closed at different levels of required military value for Case 1. We also run SHIP without a military value requirement, to determine the minimum cost solution. This yields the same solution as the 70% military value requirement. At some levels, SHIP retains Naval Submarine Base Point Loma, but does not station any submarines there. This is because military value as determined for the Navy's Configuration Analysis and used in SHIP is only a factor of the individual installation as a whole, not the complement of ships stationed there. Therefore, SHIP retains this installation for its military value but chooses not to station ships there due to the high stationing costs. This can be seen as artificially retaining an installation; SHIP must account for the fixed cost of retaining this installation to meet military value requirements, even though the installation does not retain any ships.

Closing Installations for Case 1

Installations	100%	95%	90%	85%	80%	75%	70%	no MV
Norfolk								
Little Creek								
Mayport					X			
Pascagoula		X		X			X	X
Ingleside	X	X	X	X	X	X	X	X
New London						X	X	X
Kings Bay								
Everett								
Bremerton								
San Diego								
Pearl Harbor			X	X	X	X	X	X
Guam								
Point Loma	0	0	0	0	0	X	X	X
Bangor								
North Island								
Military Value	808.87	771.79	734.37	697.29	678.66	625.40	588.32	588.32
20-yr NPV ($B)	67.85	67.77	61.72	61.63	60.43	59.98	59.89	59.89

(Column header: MV requirement)

Table 4.2. Closing Installations for Case 1. An X indicates closed installations. At some levels, Naval Submarine Base Point Loma is retained but no submarines are stationed there. This is indicated by a 0. The last two rows provide the resulting military value and 20-year NPV.

In Case 1 SHIP closes Naval Station Pearl Harbor at the 90% or below military value levels, as this is the most expensive installation in the surface and subsurface subcategory to operate. Because Pearl Harbor serves as a strategic location in the Pacific region and has the highest level of military value of all installations, we assume that it would be operationally infeasible to close this installation. Therefore in Case 2, we fix Pearl Harbor open and require that at least 25% of its capacity be filled (it is currently at approximately 40% capacity). Figure 4.2 shows the tradeoff between lowering the accepted aggregate military value and NPV, with these additional constraints. Accepting a military value at 70% of its 2005 status quo yields a 20-year net present savings of approximately $3.2 billion. For comparison, we include the data from Case 1. Lowering the required military value from 95% to 90% yields a savings of $1.2 billion. Table 4.3 shows the installations that are closed at different levels of military value in Case 2. For all further cases, we fix Naval Station Pearl Harbor open.

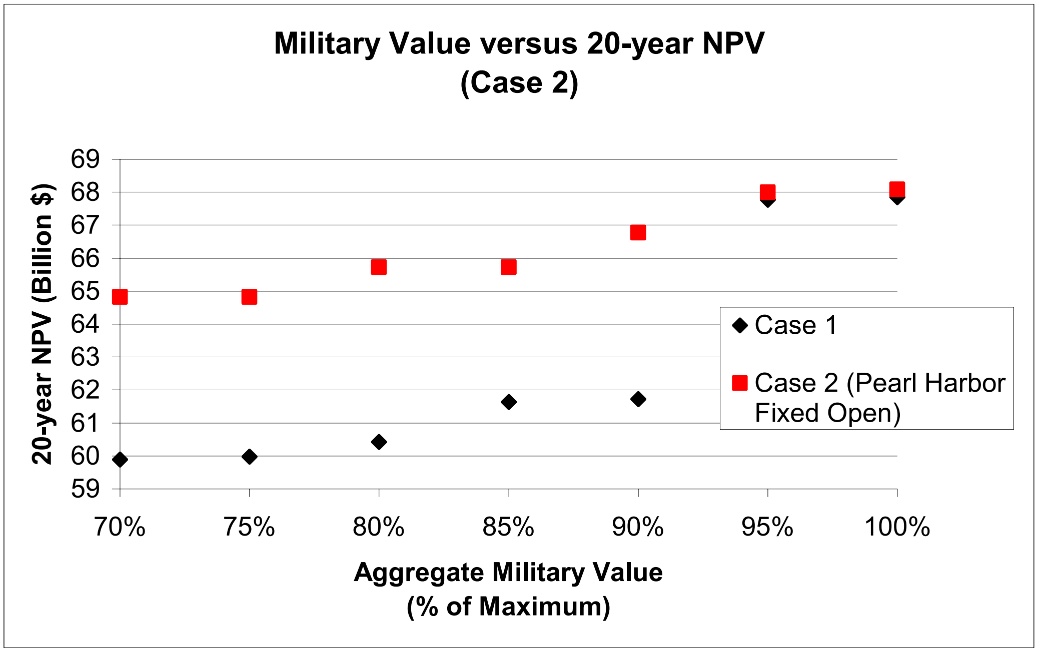

Figure 4.2. Military Value versus 20-year NPV for Case 2, with Pearl Harbor fixed open and a 25% stationing requirement. Savings at 70% of maximum military value is approximately $3.2 billion. Lowering the required military value from 95% to 90% yields a savings of $1.2 billion, as compared to $6 billion in Case 1.

Closing Installations for Case 2

Installations	MV requirement 100%	95%	90%	85%	80%	75%	70%	no MV
Norfolk								
Little Creek				X	X	X	X	X
Mayport			X	X	X	X	X	X
Pascagoula		X						
Ingleside	X	X	X	X	X	X	X	X
New London								
Kings Bay								
Everett								
Bremerton								
San Diego								
Pearl Harbor								
Guam								
Point Loma	0	0	0	0	0	X	X	X
Bangor								
North Island								
Military Value	808.87	771.79	753.16	697.26	697.26	638.97	638.97	638.97
20-yr NPV ($B)	68.08	68.00	66.77	65.73	65.73	64.82	64.82	64.82

Table 4.3. Closing Installations for Case 2, with Pearl Harbor fixed open. At some levels, Naval Station Point Loma is retained, but no submarines are stationed there. The last two rows provide the resulting military value and 20-year NPV.

D. 2005 BRAC RECOMMENDATION COMPARISONS

DoN [2005] reports initial Configuration Analysis results recommend closure of Naval Station Pascagoula, Naval Station Ingleside, Naval Base Guam, Naval Submarine Base New London, Naval Station Everett, Naval Amphibious Base Little Creek, and Naval Submarine Base Point Loma. Based on these initial recommendations, the DoN Analysis Group and Infrastructure Evaluation Group reviewed several stationing scenarios and eventually recommended Naval Station Pascagoula, Naval Station Ingleside, and Naval Submarine Base New London [DoN 2005]. The 2005 BRAC Commission only approved the closure of Naval Station Pascagoula and Naval Station Ingleside [Defense Base Closure and Realignment Commission 2005].

Some of SHIP's recommendations correspond with the DoN's recommendations. In Case 1, at 70% required military value, SHIP closes Naval Station Pascagoula, Naval Station Ingleside, Naval Submarine Base New London, and Naval Submarine Base Point Loma; this corresponds to Configuration Analysis' results. In Case 2, SHIP closes Naval Amphibious Base Little Creek, Naval Station Ingleside, and Naval Submarine Base Point Loma, which also correspond to Configuration Analysis' results.

In Case 2, SHIP closes Naval Station Mayport, which is not one of the DoN's earlier recommendations. This shows SHIP's ability to determine more cost effective alternatives while maintaining military value and operational feasibility. Because the DoN does not currently examine cost until after Configuration Analysis runs, they may not identify these alternative solutions, and cannot easily examine the tradeoff between military value and cost.

E. SHIP MOVEMENT

SHIP prescribes the movement of individual ships for each stationing scenario. Ships stationed at installations that SHIP closes must move to other installations. In addition, SHIP allows ships to move from non-closing installations if it is operationally feasible and results in a decrease in 20-year NPV. This results in more flexible stationing alternatives; an installation does not necessarily have to close for a ship to be moved to a more cost effective location. At each level of required military value, SHIP identifies the ships that move and the gaining and losing installations. Figure 4.3 shows the capacity, original stationing, and final stationing for all installations in CGEs for an 80% level of military value for Case 2. There are seven gaining and three losing installations among those that remain open. Four installations close, and one remains at its original capacity.

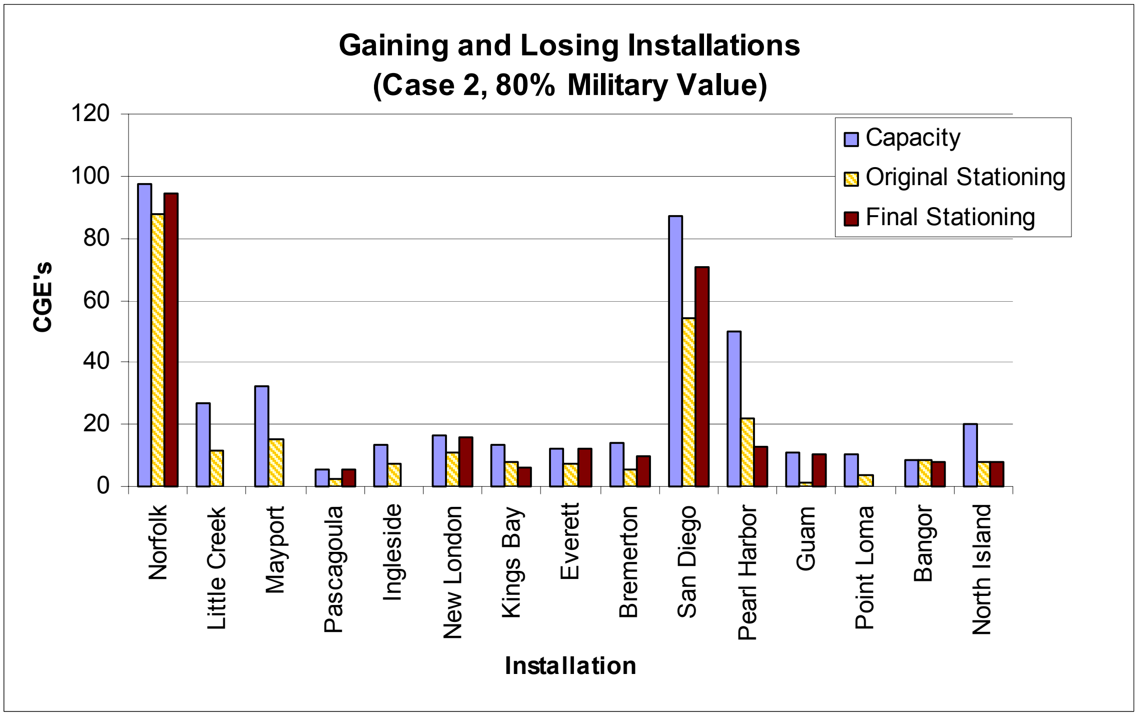

Figure 4.3. Gaining and Losing Installations at 80% military value for Case 2. This includes the capacity, original stationing, and final stationing in CGEs at all installations. This shows which installations close as well as which open installations are gaining or losing individual ships.

Across all levels of military value in Case 2, the following five installations always gain ships: Naval Submarine Base New London, Naval Station Everett, Naval Station Bremerton, Naval Station San Diego, and Naval Station Guam. With the exception of the one scenario in which it closes, Naval Station Pascagoula always gains ships. The following five installations always lose ships: Naval Station Ingleside, Naval Submarine Base Kings Bay, Naval Station Pearl Harbor, Naval Submarine Base Point Loma, and Naval Submarine Base Bangor.

Table 4.4 lists the individual ships that each installation loses and gains at an 80% level of military value for Case 2.

Ships Gained and Lost at Each Installation (Case 2, 80% Military Value)

Installation	ARS	CG	CVN	DDG	FFG	LHA	LHD	LPD	LSD	MCM	MHC	PC	SSBN	SSGN	SSN
	Ship Type														
Norfolk		+5	-2	+22	+8	-2	-4	-5							+6
Little Creek*	-2								-6			-7			
Mayport*		-4		-3	-11										
Pascagoula		-1		+1	+4										
Ingleside*										-10	-10				
New London															+6
Kings Bay													-2		
Everett		+8		-1	-3										
Bremerton		+2	+2												-2
San Diego		-7		-14	-5	+2	+4	+5	+6	+10	+10	-2			
Pearl Harbor	+2	-3		-5	+7							+9		+2	-16
Guam															+12
Point Loma*															-5
Bangor													+2	-2	-1
North Island															

Table 4.4. Ships Gained and Lost at Each Installation for Case 2 at 80% Military Value. An asterisk indicates a closing installation. A total of 135 ships moved in this scenario.

F. LINEAR FEET

The DoN data call for BRAC 2005 required installations to report their pier capacity in both CGEs and linear feet. We find the ratio of linear feet to CGEs is not consistent across all installations (Table 4.5).

Installation	CGE	Linear Feet	Linear Feet / CGE
Naval Station Norfolk	97.25	34760	357.4
Naval Amphibious Base Little Creek	27.00	13314	493.1
Naval Station Mayport	32.50	9890	304.3
Naval Station Pascagoula	5.50	2740	498.2
Naval Station Ingleside	13.50	4950	366.7
Naval Submarine Base New London	16.25	5445	335.1
Naval Submarine Base Kings Bay	13.50	11816	875.3
Naval Station Everett	12.00	6008	500.7
Naval Station Bremerton	14.00	24148	1724.9
Naval Station San Diego	87.00	23038	264.8
Naval Station Pearl Harbor	49.75	40706	818.2
Naval Station Guam	11.00	16132	1466.5
Naval Submarine Base Point Loma	10.50	6673	635.5
Naval Submarine Base Bangor	7.75	7214	824.5
Naval Air Station North Island	20.00	16818	840.9

Table 4.5. Installation Capacity in CGEs and Linear Feet. The ratio of linear feet to CGEs is not consistent across all installations.

In Case 3 we explore an alternative version of SHIP using linear feet instead of CGEs in the capacity constraints to determine if this affects the results. Figure 4.4 and Table 4.6 summarize these results. The results from Case 3 with linear feet constraints are similar to the results from Case 2 with CGE constraints; however, with lower military value requirements, Case 3 closes Naval Submarine Base New London, while Case 2 does not. This is because more excess pier capacity appears to exist when the capacity metric is linear feet, so SHIP can close more installations while still meeting pier capacity requirements. The discrepancy between the results of the two cases shows that care needs to be taken in regards to the pier capacity measure.

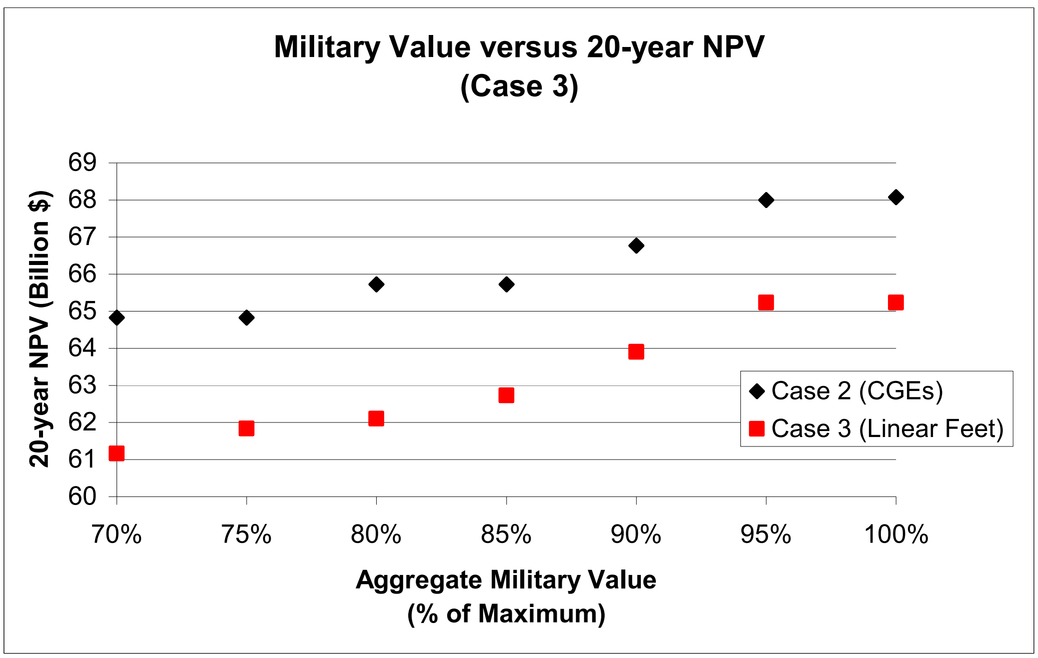

Figure 4.4. Military Value versus 20-year NPV for Case 3, with Pearl Harbor fixed open and linear feet capacity constraints. Savings at 70% of maximum military value is approximately $4.0 billion, as opposed to $3.2 billion in Case 2.

Closing Installations for Case 3

Installations	MV requirement: 100%	95%	90%	85%	80%	75%	70%	no MV
Norfolk								
Little Creek							X	X
Mayport			X	X	X	X	X	X
Pascagoula								
Ingleside	X	X	X	X	X	X	X	X
New London				X	X	X	X	X
Kings Bay								
Everett					X			X
Bremerton								
San Diego								
Pearl Harbor								
Guam								
Point Loma	0	0	0	0	0	X	X	X
Bangor								
North Island								
Military Value	808.87	808.87	753.16	702.48	651.80	644.19	588.29	537.61
20-yr NPV ($B)	65.23	65.23	63.91	62.74	62.11	61.83	61.17	60.54

Table 4.6 Closing Installations for Case 3, with Pearl Harbor fixed open and linear feet capacity constraints. Shaded blocks indicate installations that closed or had no ships stationed in Case 2. In Case 3, SHIP closes more installations at lower military value levels as there is more excess capacity when the capacity metric is linear feet.

G. ACCOMMODATING FUTURE FORCE STRUCTURE

Because SHIP incorporates individual ships, it has the ability to examine a future force structure and determine installations to retain based on future pier capacity requirements. In Case 4, we incorporate 30 additional ships into the model based on current Navy predictions for the future force structure. These ships are: LHD 8, DDG 99 through DDG 105, SSN 775 through SSN 779, CVN 77, eight littoral combat ships (LCS), and eight Zumwalt Class destroyers (DDG-1000). Figure 4.5 and Table 4.7 summarize the results of Case 4. The 20-year NPV increases by approximately $3 billion over Case 2 due to the stationing cost of the additional ships.

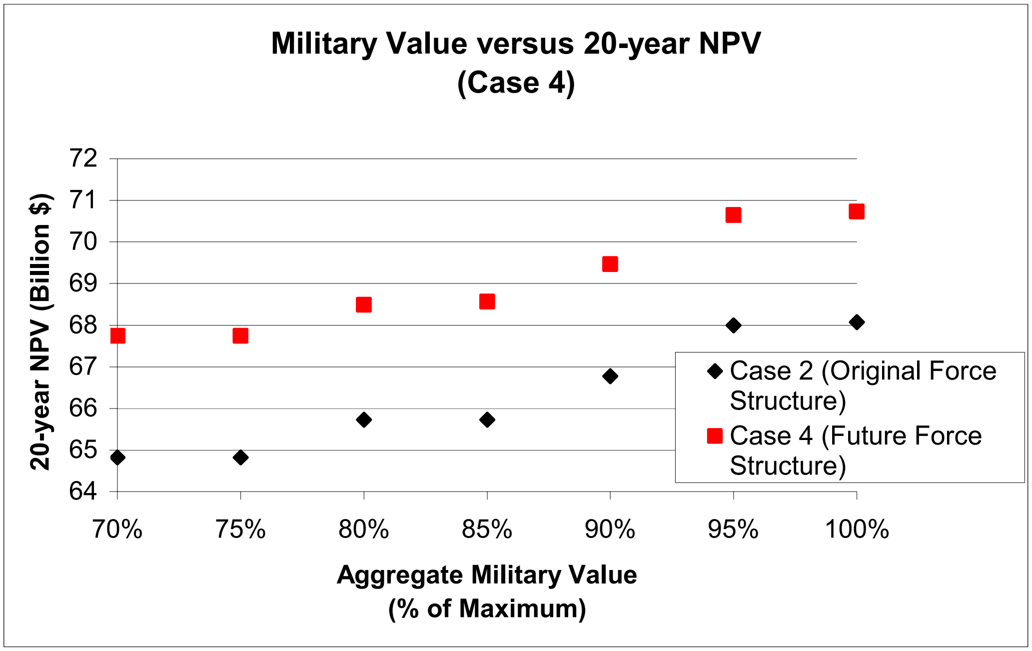

Figure 4.5. Military Value versus 20-year NPV for Case 4, with future force structure. The 20-year NPV increases by approximately $3 billion over Case 2 due to the stationing cost of 30 additional ships.

Closing Installations for Case 4

Installations	MV requirement: 100%	95%	90%	85%	80%	75%	70%	no MV
Norfolk								
Little Creek								
Mayport			X	X	X	X	X	X
Pascagoula		X			X			
Ingleside	X	X	X	X	X	X	X	X
New London						X	X	X
Kings Bay								
Everett								
Bremerton								
San Diego								
Pearl Harbor								
Guam								
Point Loma	0	0	0	X	X	X	X	X
Bangor								
North Island								
Military Value	808.87	771.79	753.16	694.87	657.79	644.19	644.19	644.19
20-yr NPV ($B)	70.73	70.65	69.46	68.56	68.49	67.74	67.74	67.74

Table 4.7. Closing Installations for Case 4, with future force structure and Pearl Harbor fixed open. Shaded blocks indicate installations that closed or had no ships stationed in Case 2. Case 4 retains different installations at lower levels of required military value due to the new complement of ships and which installations have the capability to berth them.

With higher levels of required military value, Case 4 closes the same installations as Case 2; however, at lower levels of military value, the results differ. At these levels, Case 4 retains Naval Amphibious Base Little Creek and closes Naval Submarine Base New London due to the new complement of ships and retaining installations that have the capability to berth them.

At each level of military value, we can examine the DoN's ability to meet stationing requirements if it were to expand its force structure. We define expandability as the total available pier capacity remaining after stationing the current force structure at the 15 installations included in SHIP. Decreasing the required military value to 70% of status quo yields a savings of approximately \$3 billion, but decreases expandability by half. This shows a potential risk of not having adequate pier space for additional ships. Figure 4.6 shows the tradeoff between 20-year NPV and expandability for Case 4. With the ability to model future stationing, SHIP allows current decisions to account for future pier capacity requirements.

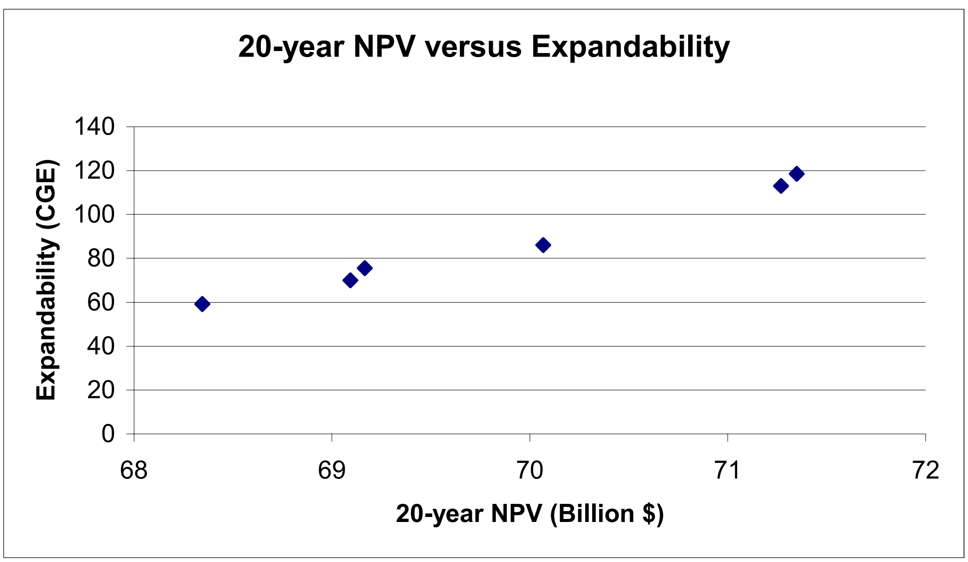

Figure 4.6. 20-year NPV versus Expandability. Expandability measures the total available pier capacity remaining after stationing the current force structure. A net present savings of approximately \$3 billion decreases the pier capacity available for expanding the future force structure by half.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

We incorporate two extensions into the Navy's Configuration Analysis to develop SHIP. By incorporating cost, SHIP provides minimum cost stationing alternatives while maintaining operational feasibility and a required level of military value. By including surface and subsurface combatants, SHIP provides more flexible and detailed stationing recommendations by allowing ship movement and recommending optimal ship placement to minimize 20-year NPV.

We examine the trade off between military value and cost. Requiring a higher level of aggregate military value leads to higher 20-year NPV. Accepting a lower aggregate military value allows the DoN to potentially realize significant savings. SHIP provides similar stationing alternatives to those recommended by the DoN for BRAC 2005. In addition, SHIP identifies alternate solutions that current Configuration Analysis does not generate, due to its exclusion of cost. This highlights SHIP's capability to determine the most cost-effective, feasible stationing alternatives. By including ships and submarines, SHIP allows for movement of individual ships between installations, regardless of whether an installation is closed or retained. This capability allows SHIP to generate alternate stationing solutions that are flexible as well as more cost effective. SHIP is also capable of stationing the proposed future force structure. With the addition of 30 new ships into the force structure, SHIP optimally stations them at installations while maintaining operational feasibility and minimizing cost. This can ensure that present day decisions account for future stationing of ships.

During BRAC 2005, the Commission approved 95% of the Army's recommendations [Huo 2006]. However, of the Navy's 21 recommendations, only 13 (61%) were approved without changes [Defense Base Closure and Realignment Commission 2005]. By incorporating cost and individual ships into their current modeling, DoN can potentially make more informed and transparent recommendations.

B. RECOMMENDATIONS FOR FUTURE STUDY

Although SHIP includes three important costs, there are other costs that can be incorporated to improve SHIP's prescription. One such cost is military construction

(MILCON) cost. This accounts for the construction of pier space or facilities at an installation. Depending on the future force structure, it might become necessary for the DoN to build new CVN- capable piers. In order to accommodate this growth, SHIP would need to incorporate MILCON costs in order to recommend MILCON at certain installations.

The DoN BRAC Data Call did not collect any of the costs used in SHIP. Therefore, all costs had to be adapted from other sources, such as COBRA, VAMOSC, and DFAS. A direct collection of cost data in the DoN BRAC Data Call for inclusion in SHIP would be helpful.

As discussed in Chapter IV, there are discrepancies in the CGE calculations. Although each installation is given the same instructions on how to calculate their CGE capacity, the ratio of CGEs to reported linear feet of pier space is not constant across all installations. The use of the linear feet metric instead of CGEs in SHIP provides different stationing solutions. This suggests care must be taken when determining which capacity metric to use.

Many of our results coincide with the DoN's BRAC 2005 recommendations. We believe this is because SHIP uses the DoN's original Military Value Analysis results. Parts of the DoN's Military Value data call are redundant with the Capacity Analysis data call. Additionally, the resulting military value numbers are not scaled linearly and do not allow for meaningful comparison between installations. If these Military Value scores were further researched and refined, we believe the DoN could provide more transparent stationing recommendations.

APPENDIX A

This appendix provides a formulation for Configuration Analysis for Surface and Subsurface Installations as used by the DoN Infrastructure and Analysis Team [2005] for BRAC 2005. It has been rewritten in Naval Postgraduate School format using notation consistent with SHIP's notation.

Indices and Sets

i	Set of installations
$i \in east$	Set of installations on the East Coast
$i \in west$	Set of installations on the West Coast
$i \in eastSSBN$	Set of installations on the East Coast that can homeport SSBNs
$i \in westSSBN$	Set of installations on the West Coast that can homeport SSBNs
$i \in eastCVN$	Set of installations on the East Coast that can homeport CVNs
$i \in westCVN$	Set of installations on the West Coast that can homeport CVNs

Parameters

<u>Parameters</u>

$rhoNumber$	penalty parameter for number of installations
$rhoExcess$	penalty parameter for retained capacity

<u>Military Value Data (units)</u>

mv_i	Military value for installation *i* (MV)
$mvAvg$	Average military value of all installations (MV)

<u>Capacity Data (units)</u>

cge_i	Pier capacity at installation *i* (CGE)
$CGEreq$	Baseline CGE requirement (CGE)
$cgeReqEast$	Baseline CGE requirement for the East Coast (CGE)
$cgeReqWest$	Baseline CGE requirement for the West Coast (CGE)
$cvnPier_i$	Number of CVN-capable piers at installation *i*

cvnReq	Number of CVN-capable piers required
cvnReqEast	Number of CVN-capable installations required for the East Coast
cvnReqWest	Number of CVN-capable installations required for the West Coast
ssbnReqEast	Number of SSBN-capable installations required for the East Coast
ssbnReqWest	Number of SSBN-capable installations required for the West Coast

Decision Variables

$OPEN_i$	1 if installation *i* remains open, 0 if it is closed

Objective Function (Maximize Military Value with penalty for open installations)

MAXIMIZE

$$\sum_i OPEN_i (mv_i / \sum_i mv_i - rhoNumber) - rhoExcess \sum_i OPEN_i cge_i / \sum_i cge_i$$

Constraints

$$\sum_i cge_i OPEN_i \geq cgeReq \qquad (1)$$

$$\sum_{i \in East} cge_i \, OPEN_i \geq cgeReqEast \qquad (2)$$

$$\sum_{i \in West} cge_i \, OPEN_i \geq cgeReqWest \qquad (3)$$

$$\sum_i cvnPier_i \, OPEN_i \geq cvnReq \qquad (4)$$

$$\sum_{i \in EastCVN} OPEN_i \geq cvnReqEast \qquad (5)$$

$$\sum_{i \in WestCVN} OPEN_i \geq cvnReqWest \qquad (6)$$

$$\sum_{i \in EastSSBN} OPEN_i \geq ssbnReqEast \qquad (7)$$

$$\sum_{i \in WestSSBN} OPEN_i \geq ssbnReqWest \qquad (8)$$

$$\sum_i OPEN_i (mv_i - mvAvg) \geq 0 \qquad (9)$$

$$OPEN_i \in \{0,1\} \quad \forall i \qquad (10)$$

APPENDIX B

This appendix provides a formulation for OSAF as used by the Center for Army Analysis [2005] for BRAC 2005.

Indices and Sets [Approximate Cardinality]

c	facility condition {green, other, vapor} [~3]
f	FCG (facility category group) [~ 40]
i	installation [~ 60]
k	maneuver land type [~ 2]
r	range type [~ 18]
u	unit [~ 600]
CA_u	set of installations where unit u can be stationed
FIX	set of installations i that are fixed open
IS_i	set of units currently stationed at installation i
N	set of ranges r requiring construction to satisfy a shortage
S	set of installations i that share training assets
UA_i	set of units u that can be assigned to installation i

Parameters

<u>Cost [units]</u>

fco_i	fixed cost of keeping installation i open [2005 \$]
fcc_i	fixed cost to close installation i [2005 \$]
fct_u	fixed cost to move unit u [2005 \$]
$bmilcon$	budget for military construction [2005 \$]
$bmove$	budget for transportation [2005 \$]
$bman$	budget for management [2005 \$]
$btotal$	total budget [2005 \$]
vcm_{fi}	MILCON for facility type f at installation i [2005 \$/SF]
vcr_{ir}	cost for a new range r at installation i [2005 \$/Range]
vcu_{fi}	cost to upgrade facility type f at installation i [2005 \$/SF]

vca_{iu}	variable cost if unit *u* is assigned to installation *i* [2005 $]
$vcse_{fi}$	cost to sustain existing facilities type *f* at installation *i* [2005 $/SF]
$vcsn_{fi}$	cost to sustain new facilities type *f* at installation *i* [2005 $/SF]
fct_{iu}	cost of moving unit *u* to installation *i* [2005 $]
$vccv_{ff'i}$	cost to convert facility type *f* into type *f′* at installation *i* [2005 $/SF]

Range [units]

$daycapn_{ir}$	range days available for range *r* at installation *i* [day]
$km2cap_{ik}$	capacity of range type *k* at installation *i* [KM^2day]
$km2req_{ku}$	required type *k* maneuver land for unit *u* [KM^2day]
$km2short_k$	allowed (existing) type *k* maneuver land shortage [KM^2day]
$daycap_{ir}$	type *r* range capacity at installation *i* [day]
$dayreq_{ru}$	type *r* range capacity for unit *u* [day]
$dayshort_r$	allowed (existing) range type *r* shortage [day]
$dayIshort_{ir}$	allowed range type *r* shortage at installation *i* [day]
$daySshort_r$	allowed range type *r* shortage for set *S* [day]
$km2Ishort_{ik}$	range overage of type k allowed at installation *i* [KM^2day]
$km2Sshort_k$	type *k* maneuver land shortage for set *S* [KM^2day]

Facility (units)

$faccap_{cfi}$	Facility type *f* capacity at installation *i* in condition *c* [SF]
$facreq_{fu}$	Facility type *f* required for unit *u* [SF]
$green_{fi}$	"Green" condition type *f* facilities not used by currently stationed units at installation *i* [SF]
$other_{fi}$	"Other" condition type *f* facilities not used by currently stationed units at installation *i* [SF]
maxpctvapor	The percent of total space for a FCG type at an installation that can be vapor (100% would allow unlimited facility space when no actual space exists) (%)

Adjusted Present Value Factor Data for Converting to NPV (time)

$apvbos$	Adjusted present value (APV) for BOS (years 1-20)
$apvbosss$	APV for BOS for steady state stationing (years 7-20)
$apvbossq$	APV for BOS for transition stationing (years 1-6)
$apvmilcon$	APV for MILCON (years 1-20)
$apvmntss$	APV for maintenance for steady state stationing (years 7-20)
$apvmaint$	APV for maintenance (years 1-20)
$apvman$	APV for management (years 1-20)
$apvmove$	APV for transportation (years 1-20)

Decision Variables

Nonnegative Variables [units]

$DAYADD_{ir}$	Deviation for range type *r* at installation *i* [day]
$KM2ADD_{ik}$	Deviation for range type *k* at installation *i* [KM^2day]
$MILCON_{fi}$	MILCON of facility type *f* at installation *i* [SF]
$UPGRAD_{fi}$	Upgrade of facility type *f* in "other" condition into "green" condition at installation *i* [SF]
$RANGE_{ir}$	number of range type *r* to build at installation *i* [day]
$AGREEN_{fi}$	"Green" condition facilities of type *f* made available by units moved from installation *i* [SF]
$USEHVY_i$	fraction of heavy maneuver land in use at installation *i*
$CONV_{cff'i}$	Conversion of condition *c* facility type *f* into type f' "green" condition facility at installation *i* [SF]
VAP_{fi}	Vapor space of FCG type *f* vacated at installation *i* from exiting unit(s) *i* [SF]

Binary Variables

$STATION_{iu}$	1 if unit *u* is assigned to installation *i*, 0 otherwise
$CLOSE_i$	1 if installation *i* is closed, 0 otherwise
$EXIT_{fi}$	1 when units move from all type *f* "other" condition facilities at installation *i*, 0 otherwise

$EXVAP_{fi}$ 1 when units move from all type f "vapor" condition facilities at installation i, 0 otherwise

Objective Function (Minimize NPV)

MINIMIZE

$$apvbosss\left(\sum_{i,u\in UA_i} vca_{iu}STATION_{iu}\right)+apvbossq\left(\sum_{i,u\in IS_i} vca_{iu}STATION_{iu}+\sum_i fco_i CLOSE_i\right)$$

$$+apvbos\left(\sum_i fco_i\left(1-CLOSE_i\right)\right)$$

$$+apvmilcon\left(\sum_{fi} vcm_{fi}MILCON_{fi}+\sum_{i\ r\in N} vcr_{ir}RANGE_{ir}+\sum_{fi} vcu_{fi}UPGRAD_{fi}+\sum_{cff'i} vccv_{ff'i}CONV_{cff'i}\right)$$

$$+apvmaintss\left(\sum_{fi}\left(vcm_{fi}MILCON_{fi}+\left(vcsn_{fi}-vcse_{fi}\right)UPGRAD_{fi}\right)\right)$$

$$+apvmaintss\left(\sum_{cff'i}\left(\left(vcsn_{f'i}-vcse_{fi}\right)CONV_{cff'i}\right)\right)$$

$$+apvmaint\left(\sum_{fi\ c\notin\{"vapor"\}} vcse_{fi}faccap_{cfi}\left(1-CLOSE_i\right)\right)+apvmove\left(\sum_{i,u\in UA_i \text{ and } u\notin IS_i} vct_{iu}STATION_{iu}\right)$$

$$+apvman\left(\sum_i fcc_i CLOSE_i+\sum_u fct_u STATION_{iu}\right)$$

Constraints

$$\sum_{u\in UA_i} facreq_{fu}STATION_{iu} \le \sum_c faccap_{cfi}+MILCON_{fi}-VAP_{fi}+\sum_{cf'}\left(CONV_{cf'fi}-CONV_{cff'i}\right) \quad \forall \quad f,i$$

$$\sum_{u\in UA_i \text{ and } u\notin IS_i} facreq_{fu}STATION_{iu} \le AGREEN_{fi}+MILCON_{fi}+UPGRAD_{fi}+\sum_{cf'}CONV_{cf'fi} \quad \forall \quad f,i$$

$$AGREEN_{fi} + UPGRAD_{fi} + VAP_{fi} + \sum_{cf'}\left(CONV_{cff'i}\right) \le other_{fi} + green_{fi} + \sum_{u \in IS_i} \sum_{i' \ne i \text{ and } i' \in CA_u} facreq_{uf} STATION_{i'u} \quad \forall \quad f,i$$

$$UPGRAD_{fi} + \sum_{f'} CONV_{\text{"}other\text{"}ff'i} \le faccap_{\text{"}other\text{"}fi} \quad \forall \quad f,i$$

$$faccap_{\text{"}vapor\text{"}fi} EXVAP_{fi} \le VAP_{fi} \quad \forall \quad f,i \qquad \text{where } faccap_{\text{"}vapor\text{"}fi} > 0$$

$$UPGRAD_{fi} \le faccap_{\text{"}other\text{"}fi} EXVAP_{fi} \quad \forall \quad f,i \qquad \text{where } faccap_{\text{"}vapor\text{"}fi} > 0$$

$$faccap_{\text{"}other\text{"}fi} EXIT_{fi} \le UPGRAD_{fi} + \sum_{f'} CONV_{\text{"}other\text{"}ff'i} \quad \forall \quad f,i \qquad \text{where } faccap_{\text{"}other\text{"}fi} > 0$$

$$AGREEN_{fi} + \sum_{f'} CONV_{\text{"}green\text{"}ff'i} \le \left(faccap_{\text{"}green\text{"}fi} - green_{fi}\right) EXIT_{fi} + green_{fi} \quad \forall \quad f,i \qquad \text{where } faccap_{\text{"}other\text{"}fi} > 0$$

$$AGREEN_{fi} + \sum_{f'} CONV_{\text{"}green\text{"}ff'i} \le \left(faccap_{\text{"}green\text{"}fi} - green_{fi}\right) EXVAP_{fi} + green_{fi} \quad \forall \quad f,i \qquad \text{where } faccap_{\text{"}other\text{"}fi} = 0 \text{ and } faccap_{\text{"}vapor\text{"}fi} > 0$$

$$\sum_{i \in S} \sum_{u \in UA_i} dayreq_{ru} STATION_{iu} \le \sum_{i \in S}\left(daycap_{ir} + DAYADD_{ir}\right) \quad \forall \; r$$

$$\sum_{u \in UA_i} dayreq_{ru} STATION_{iu} \le daycap_{ir} + DAYADD_{ir} \quad \forall \quad i \notin S, r$$

$$\sum_{i} DAYADD_{ir} \le dayshort_r \quad \forall \quad r \notin N$$

$$\sum_{i} KM2ADD_{ik} \le km2short_k \quad \forall \quad k$$

$$DAYADD_{ir} \le daycap_{ir} + daycapn_{ir} RANGE_{ir} \quad \forall \quad (i,r) \in N$$

$$\sum_{i \in S} DAYADD_{ir} \le daySshort_r \quad \forall \quad r$$

$$\sum_{i \in S} KM2ADD_{ik} \le km2Sshort_k \quad \forall \quad k$$

$$DAYADD_{ir} \le dayIshort_{ir} \quad \forall \quad i \notin S, r \notin N$$

$$KM2ADD_{ik} \le km2Ishort_{ik} \quad \forall \quad i \notin S, k$$

$$\sum_{u \in UA_i} km2req_{u\text{"}HV\text{"}} STATION_{iu} \le km2cap_{i\text{"}HV\text{"}} USEHVY_i + KM2ADD_{i\text{"}HV\text{"}} \forall \quad i \notin S$$

$$\sum_{u \in UA_i} km2req_{u\text{"}LT\text{"}} STATION_{iu} \le km2cap_{i\text{"}HV\text{"}} \left(1 - USEHVY_i\right) + km2cap_{i\text{"}LT\text{"}} + KM2ADD_{i\text{"}LT\text{"}} \quad \forall \quad i \notin S$$

$$\sum_{i \in CA_u} STATION_{iu} = 1 \quad \forall \quad u$$

$$STATION_{iu} \le 1 - CLOSE_i \quad \forall \quad i \notin FIX, u \in UA_i$$

$$\sum_{i' \notin CA_u \text{ and } i' \neq i} STATION_{i'u} \le CLOSE_i \quad \forall \quad i,\ u \in UA_i$$

$$\sum_{fi} vcm_{fi} MILCON_{fi} + \sum_{i\ r \in N} vcr_{ir} RANGE_{ir} + \sum_{fi} vcu_{fi} UPGRAD_{fi} + \sum_{cff'i} vccv_{ff'i} CONV_{cff'i} \le bmilcon$$

$$\sum_{i\ u \notin IS_i} vct_{iu} STATION_{iu} \le bmove$$

$$\sum_{i\ u \notin IS_{ii}} fct_u STATION_{iu} + \sum_i fcc_i CLOSE_i \le bman$$

$$\begin{aligned} &\sum_{fi} vcm_{fi} MILCON_{fi} + \sum_{i\ r \in N} vcr_{ir} RANGE_{ir} + \sum_{fi} vcu_{fi} UPGRAD_{fi} + \sum_{cff'i} vccv_{ff'i} CONV_{cff'i} \\ &+ \sum_{i\ u \notin IS_i} \left(vct_{iu} + fct_u\right) STATION_{iu} + \sum_i fcc_i CLOSE_i \le maxcost \end{aligned}$$

APPENDIX C

This Appendix provides the questions and weights used by the DoN for their military value data call for BRAC 2005 [Nickel 2006].

Operational Infrastructure		**Weight**
1.	Relative ability to berth multiple naval combatants	4.1488
2.	Relative number of CVNs that can be berthed in cold iron status	4.1488
3.	Infrastructure supports homeporting of SSBNs	4.1488
4.	Relative Condition of Piers	3.515
5.	Relative value of pier modernization	2.51
6.	Relative value of pier Internet Protocol (IP) infrastructure	2.008
7.	Relative Value of the on-base IM facility in terms of capability and capacity	3.515
8.	Relative value of the available drydocks in the harbor complex	3.013
9.	Relative Value of proximity to the nearest Nuclear Capable Shipyard	3.011
10.	Degaussing range available in natural harbor complex	0.686
11.	Deperming facility available in natural harbor complex	0.686
12.	Relative Pierside Crane Lift Capability	1.671
13.	Relative value of specialized security / emergency services capabilities	2.058
14.	Relative Value of ordnance handling pier capacity for your waterfront piers / wharves	2.074
15.	Relative value of on-base ordnance storage capability and capacity	0.83
16.	Relative Value of Adequate Admin Space	0.477

Operational Training		**Weight**
17.	Relative Value of proximity to the nearest shipboard firefighting facility	1.888
18.	Relative Value of proximity to the nearest damage control training facility	1.888
19.	Relative Value of proximity to the nearest submarine training facility	2.517
20.	Relative Value of proximity to the nearest ship handling training facility	0.629
21.	Relative value of throughput for all local "C", "F", and other "pipeline" schools	1.85
22.	Relative value of proximity to the nearest anti-air warfare range	3.146
23.	Relative value of proximity to the nearest naval gunnery range	2.517
24.	Relative value of proximity to the nearest submarine operating area	3.146
25.	Relative value of proximity to the nearest mine warfare training area	3.146
26.	Relative value of proximity to the nearest submarine training range	3.146
27.	Relative capability of the small arms range	0.629

Port Characteristics		**Weight**
28.	Relative value of the transit distance (safe navigation route) to sea	2.0807
29.	Relative value of the transit distance (safe navigation route) to the 50 fathom curve	2.0807
30.	Percent of the day the harbor channel allows CVN/CV transits	2.0807
31.	Relative Impact of Weather on Local Operations	0.7214

32.	Relative value of the proximity to the nearest weapons station	1.0372
33.	Relative value of the proximity to the nearest Explosive Ordnance Disposal Detachment support	0.8872
34.	Strategic Location	3.438
35.	Relative Value of Port/Harbor Restrictions on Operations	3.1117
36.	Relative value of buildings which meet structural criteria and/or perimeter standoff criteria	0.6987
37.	Adequate space for Entry Control Points to have vehicle search, holding areas, and rejection lanes	0.6987
38.	Relative value of utility (government or commercial; electric or water) redundancy	0.6987
39.	Relative value of locality cost	0.225
40.	Relative Value of proximity to the nearest Fleet and Industrial Supply Center	0.4911

Environment and Encroachment		**Weight**
41.	Relative Value of known impediments to conducting dredging operations	0.9048
42.	Relative value of land constraints at the installation and its outlying real property which restrict current operations	2.507
43.	Relative value of external encroachments which restrict operations	2.507
44.	Relative value of the costs associated with conducting the installations environmental program	0.3214
45.	Relative value of waste disposal	0.5
46.	Relative Value of potable water resource constraints	0.5
47.	Relative value of restrictions to in-water operations or testing/training activities conducted at the installation or at ranges that the installation manages due to environmental laws/regulations	1.4342
48.	Relative value of air quality control issues due to current or proposed regulations	1.0756

Personnel Support		**Weight**
49.	Located within the medical catchment area of an in-patient military medical treatment facility	1.0115
50.	Relative value of government and PPV housing availability	2.5287
51.	Relative value of community housing availability, affordability and proximity	1.9227
52.	Relative value of dependent primary and secondary education quality in the local community	0.3088
53.	Relative availability of dependant and member post secondary education in the local community	0.2647
54.	Relative opportunity for dependent/off-duty employment	0.1324
55.	Relative availability of base services	0.7331
56.	Relative availability of child development centers	0.6283
57.	Relative availability of MWR facilities	0.6283
58.	Relative opportunity for follow-on tour in the homeport	0.0441

59.	Relative proximity to a population center/city that has a population greater than 100,000	0.0882
60.	Relative proximity to a nearest commercial airport that offers regularly scheduled service by a major airline carrier	0.5768
61.	Relative local crime rate	0.1324

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